Carbon Nanotubes as Nanoscale Mass Conveyors

Atom Transport at the Nanoscale

In a development that brings the promise of mass production to nanoscale devices a bit closer, Lawrence Berkeley National Laboratory scientists have used carbon nanotubes to ferry atoms over microscopic distances. In their demonstration experiment, which was performed inside a transmission electron microscope, they used small electrical currents applied to a carbon nanotube to move indium atoms along the tube from one end to the other. This work marks another step towards the high-throughput construction of atomic-scale optical, electronic, and mechanical devices that will fulfill the promise of nanotechnology.

Developing methods that can move atoms and nanosized particles to precise locations has been an ongoing challenge for nanotechnology. Single atom manipulation was demonstrated as early as 1990 when IBM researchers spelled out the company logo by positioning 35 xenon atoms with a scanning tunneling microscope (STM). However, as fabrication tools, both STM and the related atomic force microscopes (AFM) suffer from a loading deficiency: although they can manipulate atoms already present, they cannot efficiently deliver atoms to the work area. Carbon nanotubes, on the other hand, with their hollow cores and large aspect ratios, are natural candidates for conduits for nanoscale materials. In this case, the challenge is in developing methods to achieve controllable, reversible atomic scale mass transport along the nanotube walls.

The work here took advantage of electromigration, a phenomenon of critical importance to the semiconductor industry. The team thermally evaporated the species to be transported, indium metal, onto a bundle of carbon nanotubes at levels so small that it populated the tubes' surfaces as isolated indium nanocrystals. The bundle was then placed inside a transmission electron microscope, where one end of the nanotubes was attached, via conducting adhesive, to a metal holder and a tungsten tip mounted on the end of a nanomanipulator made contact with the other end. Voltage was applied across the tube sending an electrical current through it. This generated thermal energy that heated and melted the indium particles. By carefully controlling the electrical current, indium atoms could be made to move from one indium particle to another further down the tube. In the example shown in the series of images in the figure, indium particles shrink and then disappear at the left, while particles to the right grow. Several seconds later, the newly enlarged particles also disappear, replaced by others even further to the right, as would be expected if the indium atoms are indeed moving from left to right.

It was demonstrated that thermally activated, electrically driven indium atoms could move substantial distances along the nanotube, until all of them pile up at the end of the nanotubes as a single crystal. Moreover, reversal of the voltage polarity drives the particles back to their starting point. Repeated transits back and forth across the tube conserve indium atoms (the indium does not evaporate), a requirement if the process is to be used to deliver valuable material to a worksite.

With this successful first step, one might imagine arrays of nano-sized conveyor belts delivering mass to specific locations atom-by-atom or picking up material at one site and delivering it to another. In this sense, the work is a demonstration of a prototype of might be developed into a formidable nanoassembly tool.

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